INFLUENCE OF TOOLPATH AND CLAMPING STRATEGIES ON STAINLESS STEEL PLATES DISTORSION AFTER MACHINING

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Abstract

Heat exchangers in nuclear power generation plants are made of thin stainless-steel plates assembled together in order to improve their efficiency and compactness. To ensure the assembly, the global distortion of those plates must be mastered and minimized, mainly by predicting the evolution of the residual stress field during their manufacturing process chain. The residual stresses generated during rolling are removed by heat treatments process that also induce another stress field while cooling. During machining, those residual stresses are redistributed to reach another equilibrium state, leading to a macroscopic part distortion. The objective of this work is to study the influence of the machining toolpath and clamping strategies on the global part distortion so as to optimize the manufacturing process chain.

Key Words: Residual Stresses, Toolpath Strategy, Clamping Strategy

1 Introduction

New generation of nuclear exchangers includes the use of thin plates sized 2000*1000*5 mm^3. In order to improve their corrosion resistance, they are made of stainless steel 316 L, a refractory material which is difficult to machine. At the end of the manufacturing process, the plates are grooved by milling technique. The residual stress field is then redistributed and new stresses are introduced at the surface of the material.

The factors having an influence on this distortion are numerous and some authors already studied them. [L. Liangbao 2015], using the layer removal method coupled with numerical simulations, highlights the existence of a rate of material removal beyond which the distortion stabilizes. According to him, the first passes are those that induce the main distortion.

[K.H Fuh and C.F Wu 1995] were the first to study the influence of cutting parameters on the introduction of residual stresses while machining. They concluded that strong cutting conditions induce high residual stresses on the surface of the material. The influence of cutting conditions will not be studied in this document.

[S. Hassini 2015] and [X. Cerutti 2014] studied the influence of clamping strategies. They showed that the number of clamps has a negligible influence on the global distortion, but has an impact on dimensional tolerances. Their conclusions are similar regarding the influence of toolpath strategy.

2 Experimental methodology

2.1 Samples geometry

The geometry of samples was defined by applying a 5-ratio homothetic transformation on the dimensions of industrial parts. Figure 1 shows the comparison between industrial parts and academic samples. It also presents the rolling and machining directions that have been kept normal.

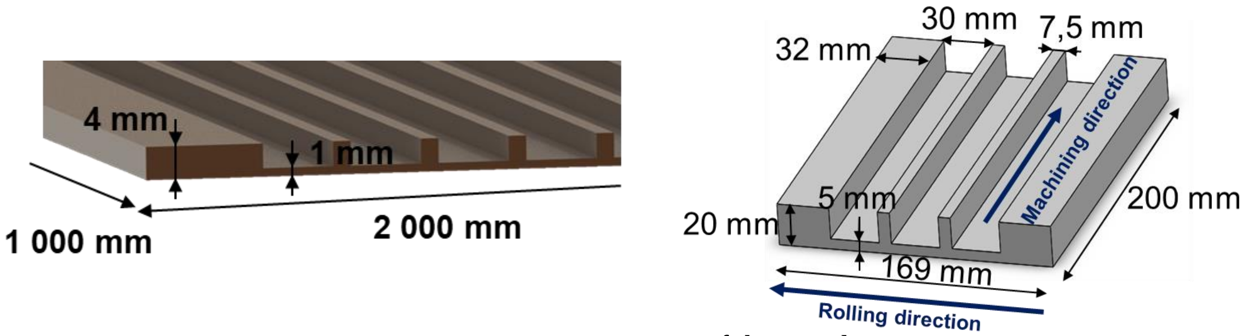


Figure 1: Geometry of the samples

2.2 Test plan

This work only focuses on the influence of a few parameters of clamping and machining strategies. The influence of cutting conditions such as the cutting speed V_c (130 m/min), radial depth of cut a_e (30 mm) or lubricant (central emulsion lubrication) has not been studied and thus were kept constant for the whole test campaign. Prior tests were realized according to “Tool Material Couple” method to validate cutting parameters values and to ensure cutting stability. Table 1 presents the tests that have been carried out.

		Toolpath	Feed per tooth (mm/rev/tooth)	Axial depth of cut (mm)	Initial clamping force per screw (kN)
Influence of initial clamping force	Test #1	LMR	0.12	1	5
	Test #2	LMR	0.12	1	10
	Test #3	LMR	0.12	1	20
Influence of depth of cut	Test #2	LMR	0.12	1	10
	Test #4	LMR	0.03	3	10
Influence of toolpath	Test #2	LMR	0.12	1	10
	Test #5	MLR	0.12	1	10

Table 1: Test plan

L, M and R stands for the designation of the grooves (Left, Middle, Right) as shown in Figure 3a, the order corresponding to the machining order.

3 Experimental means

3.1 Instrumented clamping system

During machining, the parts are located and maintained by an isostatic instrumented clamping system. The positioning is ensured by the dynamometric platform, a grinded wedge and a punctual contact. Figure 2 presents the various components of the clamping system. Different force sensors are used: the 9255A piezoelectric Kistler dynamometric platform allows to measure the forces generated during machining in the three spatial directions. It is then possible to determine the cutting force and to control the tool wear. The Kistler load washers measure the instantaneous clamping force in each screw. These values give information about the part behavior during and after machining. The measurement error of load washers has been determined during their calibration. The value depends on the range of efforts applied and represents in this case 0.5%. To overcome this issue, an acquisition reset is made every pass (for f_z=0.02 mm/rev/tooth) or every five passes (for f_z = 0.12 mm/rev/tooth) and the gain or loss of efforts is calculated relatively. It also allows to reduce the electrical drift which reaches 1.5 N for 100 seconds which is the duration between two resets.

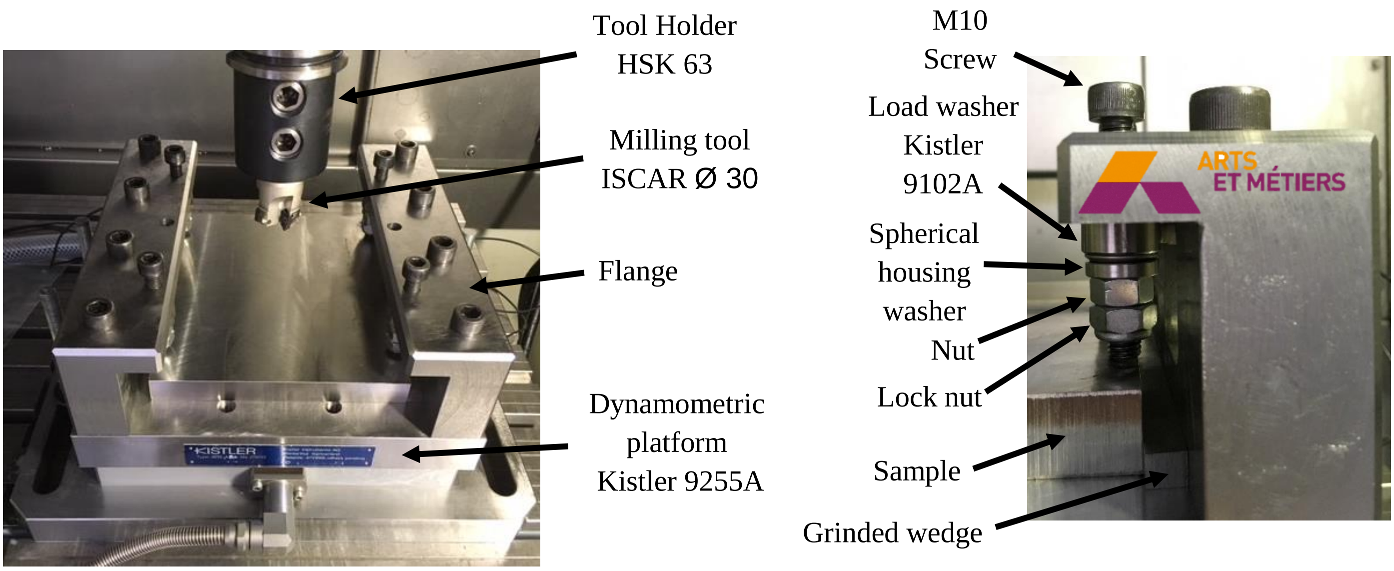


Figure 2: Instrumented clamping system

3.2 Geometrical control of parts

The geometrical control of parts is done with a DEA Coordinate Measuring Machine (CMM) for which the uncertainty of measurement is ± 2 µm. Each part is measured in three different steps: before machining, after machining clamped, after machining unclamped. The positioning as well as the measurement program are the same for all parts in order to ensure the repeatability.

3.3 Preliminary tests

To ensure the repeatability of the experiments, three parts were machined in similar conditions. The distortion profile is studied in a plane (XZ) located at y = 100 mm as shown in Figure 3a.

The maximum difference between the flatness defects of superior faces is about 8% which is negligible comparing to the next results. The repeatability being ensured, each test presented in Table 1 was realized once.

A temperature instrumented test has been carried out in order to ensure that the values measured by the load washers are due to the redistribution of residual stress within the material and not due to the dilatation of some components. The part as well as two clamping screws have been instrumented with K-type thermocouples. A 2°C increase in temperature is observed into the part leading to an expansion in the thickness of 0.7 µm. This dimensional variation can be neglected because it is offset by the different components and particularly by the spherical housing washers.

4 Results and discussion

4.1 Influence of initial clamping force

Three levels of initial effort have been tested (5, 10 and 20 kN per screw). A range of mounting and clamping have been implemented. The profiles of distortion obtained are presented in Figure 3b.

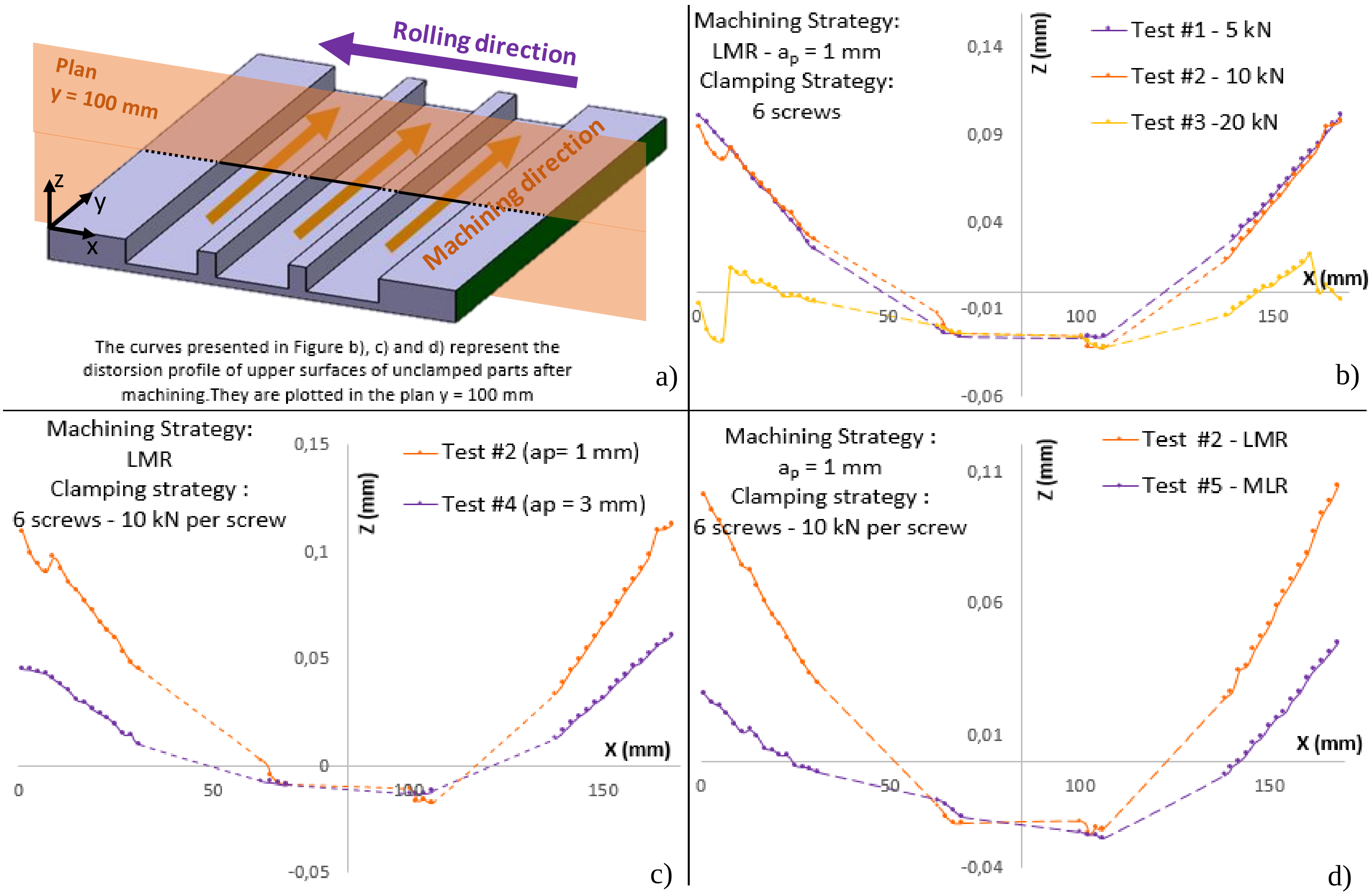


Figure 3: Distortion profiles according different cutting parameters
a) Notations
Distortion profile according to:
b) Initial clamping force - c) Axial depth of cut - d) Toolpath

The distortion profile is similar for an initial clamping force of 5 or 10 kN per screw. By increasing it up to 20 kN, the global distortion is lower. The clamping forces create a stress field into the part which superimposes to the residual stresses field. While machining, the residual stresses are reorganized and the superposition of both stress fields can locally reach the elastic limit and induce plasticity. This hypothesis will have to be confirmed with numerical simulations.

4.2 Influence of axial depth of cut

As shown in Figure 3c, the depth of cut has a great influence on global distortion. This could be explained by the residual stress distribution into the part. This one has been determined with the X-ray diffraction method. The thickness of the compression layer is 0.5 mm. Between 0.5 mm and 2 mm, the stress is slightly positive. When removing a 1-mm layer, the traction-compression ratio in this layer is unbalanced, leading to a great distortion. On the contrary, a 3-mm layer is more balanced causing less distortion after machining.

The experiments also prove that the depth of cut has a great influence on the sequence effect. Figure 4 describes this effect: as the part deforms while machining, the sides of stiffener progressively lose their parallelism and some areas are machined at several passes.

Figure 4: Sequence effect on stiffener sides

Figure 5 shows the cartographies of the dimension of the left groove for depths of cut of 1 and 3 mm.

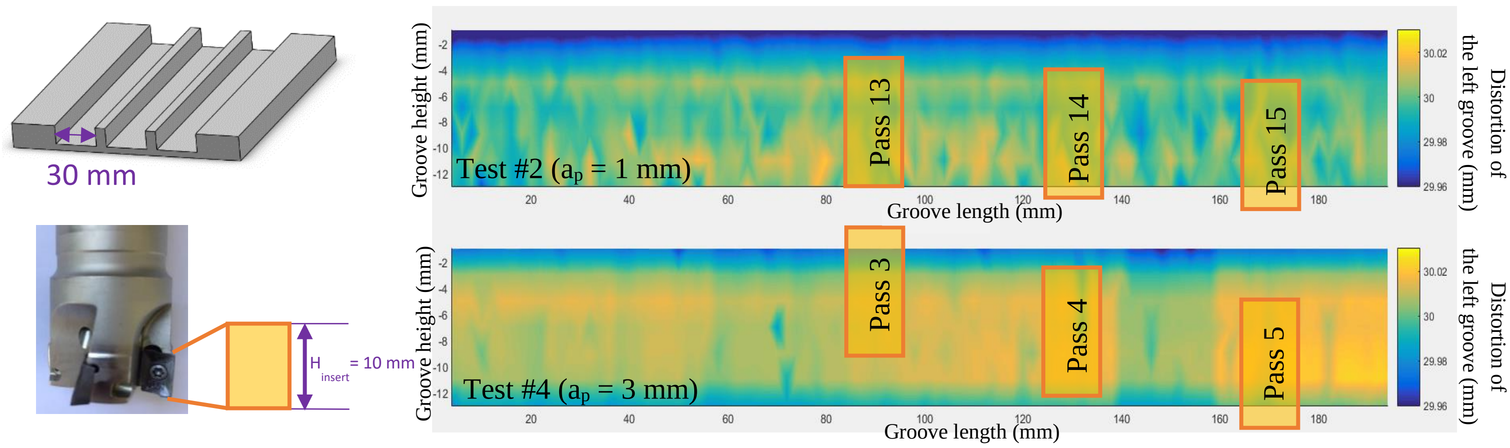


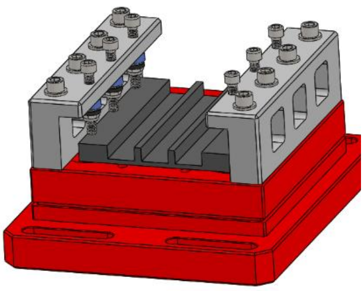
Figure 5: Cartographies of the dimension of the left groove

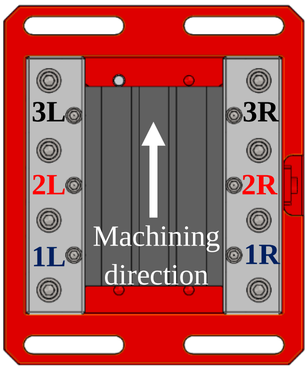
For test #2, during the first 10 passes, the tool successively machines the sides of the groove, countering the effect of distortion. Furthermore, during the 5 last passes, the 10 mm-height of the tool does not allow to machine the sides in the first 5 mm: the distortion can be seen in this area, the dimension is lower than the theoretical 30 mm. In the case of test #4, only the first 2 mm are subject to the distortion.

4.3 Influence of toolpath strategy

The distortion profile, available in Figure 3d, shows that toolpath has a great influence on it. This observation is in contradiction with the ones of [X. Cerutti 2014] and [S. Hassini 2015]. The asymmetry induced by the LMR strategy leads to a greater distortion.

Load washers highlight a heterogeneity of the redistribution of residual stresses while using the asymmetric strategy LMR. As shown in Figure 6, the gain of clamping force between the beginning and the end of the test is unbalanced: the washers on the right gain 257 N whereas the left ones lose 54 N.





	LMR Strategy (Test #2)	MLR Stratgey (Test #4)
$\sum_{k\in\{1R;2R,3R\}} (Fb_f - Fb_i)_k$	257 N	143 N
$\sum_{k\in\{1L;2L,3L\}} (Fb_f - Fb_i)_k$	-54 N	206 N

with Fb_f the final clamping effort
Fb_i the intial claming effort

Figure 6: Results from load washers

5 Conclusion

Hypotheses can be proposed to explain certain phenomena such as influence of the depth of passage, the machining path and the initial clamping force. The different tests highlight the great influence of clamping and machining on global part distortion. Using the strong clamping forces and a large depth of cut allow to reduce it significantly. By contrast with the conclusions of [S. Hassini 2015] and [X. Cerutti 2014], toolpath strategy also seems to influence the part behavior and the redistribution of residual stresses. An asymmetric strategy increases the distortion and unbalances the redistribution of residual stress field.

These experimental results will be used to build and fit numerical models. These will be determinant to understand the phenomena highlighted experimentally and to validate the different hypothesizes presented in this paper.

6 Acknowledgement

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